Comment on "Two-dimensional charged-exciton complexes" by Varga, K – Reply

A. Thilagam
Faculty of Science
Northern Territory University
Darwin NT 0909
Australia

Abstract

We respond to criticisms raised by K. Varga (cond-mat/9802262) and reaffirm that the results in our original paper obtained using a two-body analytical method remains valid within the framework of an effective excitonic composite model. The conceptual model of the excitonic systems as well as the numerical method based on variational functions utilized by Varga differ significantly from ours. Hence comparison of binding energies of the charged-biexciton remains questionable. In this reply, we discuss the shortcomings of modelling the charged-biexciton as a five-body system and treating excitonic complexes as atomic systems, as done in Varga's Comment. We also clarify the somewhat misleading statement that the "charged-biexciton complex is stable for any value of the mass ratio" in our original paper and derive a simple criterion for the existence of a single bound charged-biexciton state.

In his Comment, Varga has used a AAB-type three-body and AAABB-type five-body system to model the charged exciton and charged biexciton respectively. These excitonic systems have been modelled as an AB type Coulomb problem in our work [1]. This is done by formulating the two-body method (Eqs (15-19) in our original paper) so that a radial Schrodinger equation is obtained in which the potential is not the real two-body potential, but the average potential of a three- or five-body system. With the use of an effective mass and dielectric constant, the resulting radial equation approximates the problem of an exciton complex interacting with holes and electrons in the valence and conducting bands respectively. K. Varga in his Comment has critized this two-body approach and questioned the validity of our results obtained for the charged-biexciton system.

We have modelled the charged-biexciton as a two-body system (biexciton + e or h) - justifying calculations based on the analytical expressions derived for the charged exciton (exciton + e or h). The biexciton is conceptualized as a single hydrogenic composite system; the advantage being that experimental estimates of the biexciton binding energy (ref. 19,20 of our paper) can be used to estimate energies of the charged-biexciton complex. Due to the semi-empirical nature of our charged-biexciton model, we firmly disagree with the Comment that an over simplified model has been used in our work.

Varga's Comment uses a stochastic variational method based on correlated Guassian basis sets [2]. Unlike the semi-empirical charged biexciton model used in our work, this method treats excitonic systems in solid materials just like atomic systems (e.g. H_2^+ and H_3^+) which casts doubts on the values of binding energies obtained for the charged-biexciton. Due to the lack of analytical forms [3] for the Bloch functions, it is almost impossible to determine the correct dielectric function and hence the correct Coulomb potential between the electrons and holes in a charged biexciton. The choice of a suitable variational wavefunction to calculate the binding energy of a highly complex system like the charged-biexciton is thus a difficult one to make. This constrast with our heuristic approach[1] in

which most of the properties of the solid are coalesced into the effective masses and dielectric contant of the interacting electron and hole. Thus the sensitivity of assumed forms of variational functions on calculated results as well as the role of the geometrical structure [4] and hidden symmetry [5] in stabilizing the charged exciton complex have to be fully explored before a definitive statement about the stability of the charged-biexciton is made.

In this respect, we point out a misleading statement in our original paper[1]. The sentence that the "charged-biexciton complex is stable for any value of the mass ratio" which appears under "Results and Discussion" is somewhat misleading. It should be noted that eq.25 which specifies the *upper bound* in the ratio of binding energy of the charged exciton to charged biexciton, (stated in the paragraph preceding Eq.25) should correctly be an inequality ($\leq$ instead of $=$ in Eq.25). Hence Eq.25 does not ensure the existence of *at least one bound state*. A simple and efficient criterion for the existence of a single bound state can be obtained using eq.24:

$$Eb_{X_3^-} = (\frac{M_{X_3^-}}{M_{R'}} \frac{\epsilon_{2ex}^2}{\epsilon_{X_3^-}^2} - 1) Eb_{2ex}, \tag{1}$$

Using relations derived for a biexciton [6], $M_{R'} \approx \frac{2}{3}\mu_{ex}$ and $\epsilon_{2ex} \approx \frac{\sqrt{2}}{4-\sqrt{2}}\epsilon_{ex}$, and eq.(1), we get a sufficient condition for the existence of charged-biexciton states:

$$\gamma_i > 2.23 \quad \text{where } \gamma_i = \frac{M_{X_3^i}}{\mu_{ex}} \frac{{\epsilon_{ex}}^2}{{\epsilon_{X_3^i}}^2} \tag{2}$$

where i=+ or -, depending on the charge of the charged-biexciton. $\gamma_+ > \gamma_-$ due to the larger mass of holes and thus the positively charged-biexciton is relatively stable compared to its negatively charged counterpart. Unlike in three dimensional systems, two-body bound states have been shown [7, 8] to occur even for arbitrarily small attractive potentials in two and one dimensional systems. This fact was well demonstrated by recent experiments [9] which showed that a finite exciton binding energy remains present up to very high free-carrier concentrations. Extending the results of these works to eq.(2), we can expect at least a single bound state of the charged-biexciton (X_3^- and X_3^+) for small values of σ. This is in contradiction to the results in Varga's Comment.

References

[1] A. Thilagam, Phys. Rev. B**55**, 7804 (1997).

[2] K. Varga and Y. Suzuki, Phys. Rev. C**52**, 2885 (1995).

[3] G. Bastard, "Wave Mechanics Applied to Semiconductor Heterostructures", Les Editions de Physique, France (1988)

[4] J. R. Chapman, N. F. Johnson and V. Nikos Nicopoulos, Phys. Rev. B**55**, 10221 (1997).

[5] J. J. Palacios, D. Yoshioka and A. H. MacDonald, Phys. Rev. B**54**, 2296 (1996).

[6] J. Singh, D. Birkedal, V. G. Lyssenko and J. M. Hvam, Phys. Rev. B**53**, 15909 (1996)

[7] F. Stern and W. E. Howard, Phys. Rev. **163**, 816 (1967).

[8] L. D. Landau and E. M. Lifshitz, "Quantum Mechanics : non-relativistic theory", Pergamon Press, p.163, 1977

[9] M. Kemerink, P. M. Koenraad, P. C. M. Christianen, R. van Schaijk, J. C. Maan and J. H. Wolter, Phys. Rev. B**56**, 4853 (1997)